SPACELAB INDUCED ENVIRONMENT TECHNICAL OVERVIEW†

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1. INTRODUCTION

Much has been written in recent years on the subject of the Space Transportation System (STS) Space Shuttle Orbiter induced contaminant environment and its ultimate impacts upon scientific instrumentation and sensitive systems flown as payloads within the Orbiter payload bay[1-3]. Equally as important is the induced environment of the STS Spacelab vehicle being designed and developed by the European Space Agency as a prime Shuttle payload. This will be additive to the environment of the Shuttle Orbiter and must be considered as a primary design parameter in the Spacelab development. Proper contamination control of the Spacelab vehicle is potentially even more critical than for the Shuttle Orbiter due to its inherent close proximity to scientific instrumentation within the payload bay. The National Aeronautics and Space Administration's Marshall Space Flight Center recognized this area of concern early in the Spacelab Program and funded several Spacelab contamination modeling and analysis studies to predict the Spacelab induced contaminant environment, determine its compliance with program contamination control criteria and establish recommended contamination abatement procedures and on-orbit operations.

This paper presents a compilation of the results of a systems level contamination analysis and related computer modeling activities conducted by Martin Marietta Aerospace, Denver Division under contract NAS8-31574. It depicts our current technical assessment of the contamination problems anticipated during the Spacelab program and presents recommendations for contamination abatement designs and operational procedures based upon experience gained in the field of contamination analysis and assessment dating back to the pre-Skylab era.

The impact of the induced contaminant environment of space vehicles has become extremely important as a basic design parameter for the multi use/variable configured Spacelab carrier and it numerous ultrasensitive payloads. The degree of efficiency to which the Spacelab design meets the contamination control criteria as dictated by the Spacelab payload user

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community will determine the ultimate utility of the Spacelab to provide this community with the platform from which to conduct desired investigations with assurance that the induced environment will not compromise payload objectives.

2. SPACELAB MODELING AND ANALYSIS

2.1 Major Model Parametric Considerations - A primary design goal for the various Spacelab configurations is to insure that the operation of Spacelab/Orbiter systems and the mission objectives of scientific instruments are not compromised by the induced molecular and particulate contaminant environment emanating from the Spacelab carrier. To accomplish this, a rigorous computer modeling and analysis study has been conducted over the past 3½ years to establish the predicted on-orbit contaminant environment levels under variable orbital conditions as well as to determine Spacelab contamination related design and operational requirements necessary to meet the maximum allowable induced environment levels or criteria as set forth in Volume X of JSC 00770[4]. These criteria have also been recommended for application as a design goal for Spacelab by the European Space Agency (ESA) in ECR 00049[5]. The criteria state that it is a design and operational goal for Spacelab to control:

a. in an instrument field-of-view particles of 5 microns in size to one event per orbit;

b. induced water vapor column density to 10^{12} molecules$\cdot$cm^{-2} or less;

c. return flux to 10^{12} molecules$\cdot$cm^{-2} s^{-1};

d. continuous emissions or scattering to not exceed 20th magnitude$\cdot$s^{-2} in the UV range; and

e. to control to 1% the absorption of UV, visible, and IR radiation by condensibles on optical surfaces.

This set of criteria is compatible with the contamination control criteria imposed upon the Orbiter[4] and has been utilized as the baseline from which to make Spacelab design and development decisions throughout this paper. These criteria have been used as a basis in the modeling activities to establish a compatible model output format which facilitates the understanding of the criteria implications and aids in the performance of contamination evaluation studies.

Because of the dependence of the current model format upon the above contamination control criteria, it is important to note the additional assumptions and interpretations that are required to make the abbreviated criteria statements more applicable and useful in design and development evaluations. These interpretations will demonstrate the reasoning behind certain modeling decisions and approaches discussed in ensuing sections of this paper. In his memo of May 24, 1976[6], R. Naumann of the Marshall Space Flight Center (MSFC), chairman of the Contamination Requirements Definition Group (CRDG) presented the necessary additional interpretations of these criteria that were established by the cognizant scientific user community. These interpretations are discussed in detail in Section 4 herein.

The primary analytical tool utilized in this study was the Shuttle/Payload Contamination Evaluation Program (SPACE) which was developed to mathematically synthesize the contaminant sources, susceptible surfaces and transport mechanisms and to establish the predicted induced contaminant environments of the Spacelab carriers modeled. The general modeling considerations and approaches employed herein are discussed in Reference 7. In the subsections that follow, brief descriptions of the current Spacelab modeled configurations, contaminant sources and major SPACE Program input parameters and assumptions are presented.

2.1.1 Modeled Spacelab Configurations - The current SPACE Program developed primarily for static design and development analysis consists of three unique Spacelab configurations deemed representative of the assorted module and pallet hardware combinations that will be utilized throughout the Spacelab Program. The current Spacelab configurations modeled include: 1) the long module/one pallet (LMOP); 2) the short module/three pallet (SMTP); and 3) the five pallet (FIVP) configurations. Geometrical data utilized in establishing the necessary model input parameters for these configurations was obtained from Reference 8. Figure 1 illustrates the basic LMOP configuration elements utilized in the geometrical modeling. Note that the axis system and station numbers (X_o, Y_o, Z_o) presented are consistent with those of the Shuttle Orbiter coordinant system which is a baseline for this paper. The primary purposes for developing the geometrical configurations are to establish the spatial relationships between all Spacelab contaminant sources and surfaces and to obtain mass transport factors (MTF). The MTF represents the percentage of mass leaving a Lambertian source or surface capable of reaching another point or surface based upon geometry and surface shadowing between sources and receivers. When input into SPACE, the MTFs formulate the basis for describing the Spacelab induced contaminant environment.

Obtained from Reference 8

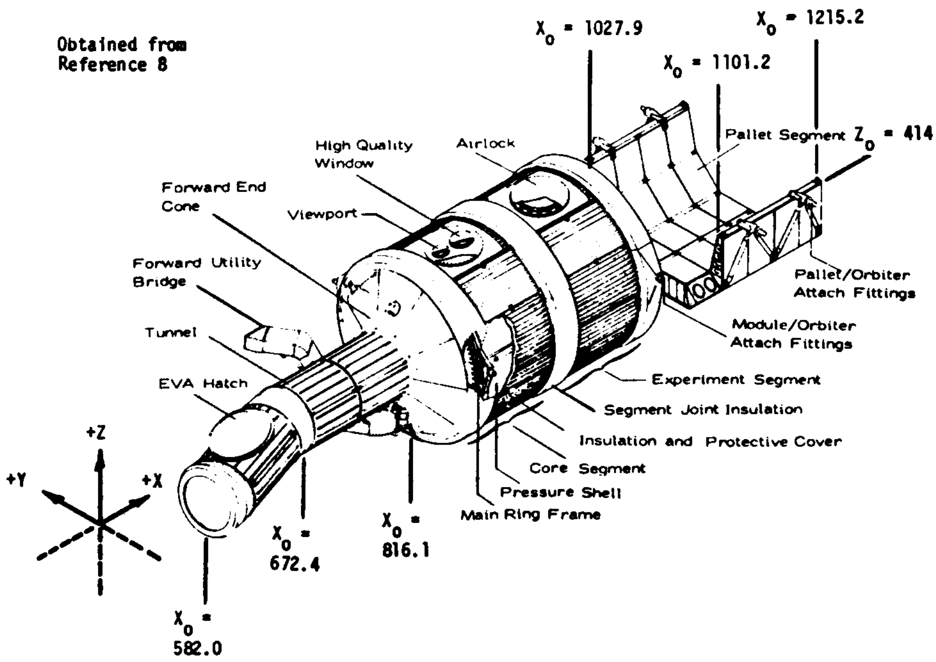


Figure 1. Baseline Long Module/One Pallet Reference Spacelab Configuration (LMOP)

The three modeled Spacelab configurations were segmented nodally and displayed graphically by the computer as depicted in Figure 2. The nodal breakdown of each configuration is used as the prime reference system between the configuration and contaminant source parametric data such as the materials mass loss characteristics and surface temperature profiles discussed later. A specially modified Martin Marietta Thermal Radiation Analysis System (TRASYS-II)[9] is utilized to establish the necessary geometrical relationship input data to the SPACE Program, however, almost any properly modified configuration model could probably be used in its place. Once the required relationships are established, this segment of the model is no longer needed.

However, any changes in geometrical relationships between surfaces and sources, require new relationships to be established from the TRASYS II program.

In order to establish consistency between the three modeled configurations, they were each located within the Orbiter payload bay envelope between $X_o = 582.0$ and $X_o = 1215.2$, as depicted in Figure 2. It is realized that hardware locations within the bay will vary depending upon center-of-gravity considerations, but the envelope utilized establishes a consistent base for analytical comparisons. The payload bay surfaces (representative of the Orbiter payload bay liner) shown in Figure 2 are included in the model for surface shadowing characteristics but are not chargeable to the Spacelab induced environment.

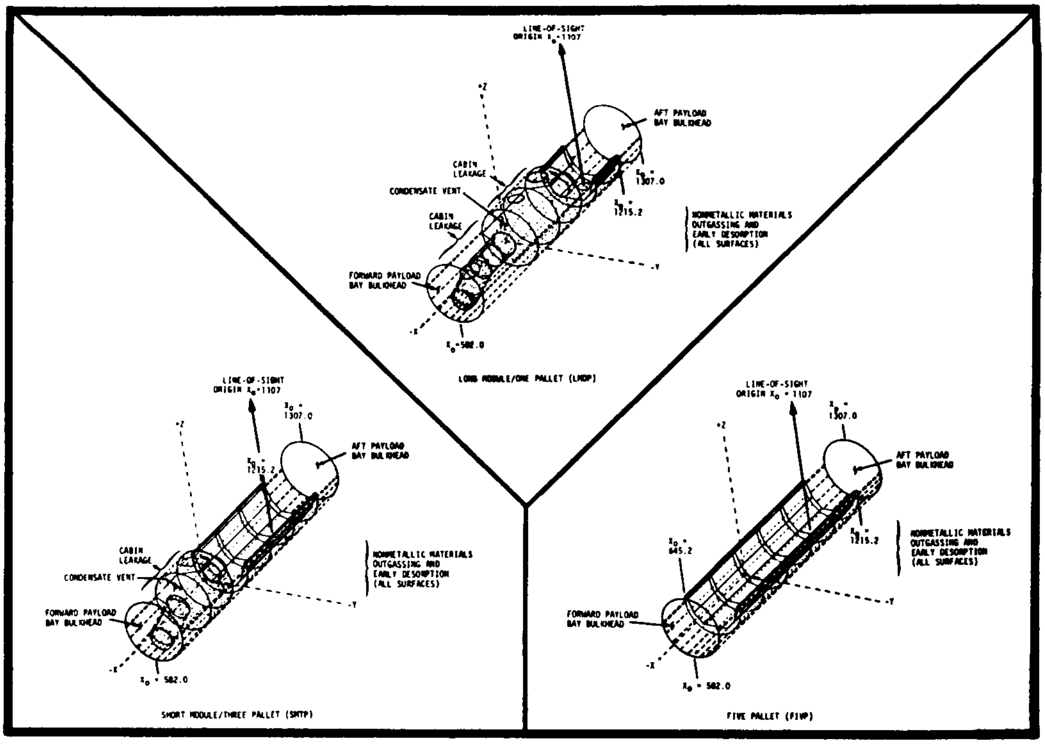
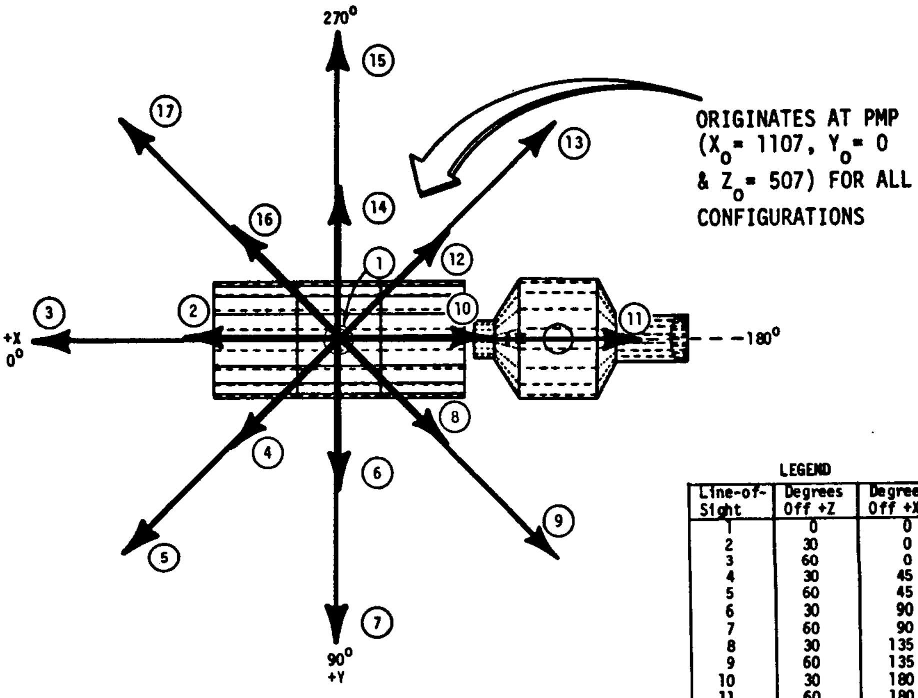


Figure 2. Modeled Spacelab Configurations and Contaminant Sources

The SPACE Program not only considers contaminant transport directly between a source and a receiving surface but also evaluates the physics of the contaminant cloud in the near vicinity of the Spacelab. The major items included therein are the phenomena of the column density or "thickness" of the induced environment through which a payload must view and the return flux (or backscatter) of released contaminant molecules to a surface of interest resulting from molecular collisions with the ambient atmosphere or with other contaminant molecules (self-scattering). To evaluate these phenomena, seventeen (17) lines-of-sight for each Spacelab configuration have been geometrically modeled. Along each of these lines-of-sight which originate at $X_o = 1107$, $Y_o = 0$ and $Z_o = 507$ (Figure 2), a series of pseudo surfaces were input to the model as point contaminant receivers. The point of origination is consistent with the Prime Measuring Point (PMP) advocated by the CRDG at MSFC for contamination control criteria evaluation. The lines-of-sight currently modeled were selected to uniformly encompass a 120 degree conical viewing volume around the +Z axis above the Spacelab configurations as illustrated in Figure 3 for the SMTP. This is also consistent with the CRDG interpretation of the contamination control criteria and encompasses the majority of viewing requirements of Spacelab payloads to be flown.

2.1.2 Spacelab Contaminant Sources - The modeled Spacelab carrier configurations currently have four major contaminant sources identified which have been evaluated in detail. These include: 1) external nonmetallic materials outgassing (i.e.; the long term mass loss of the material upon exposure to space vacuum); 2) early desorption from external surfaces (i.e.; the initial high mass loss of adsorbed and absorbed volatiles, gases and liquids); 3) cabin atmosphere leakage from pressurized tunnel and module segments; and 4) the Spacelab Condensate Vent (SCV). Figure 2 should be consulted for the locations of the modeled contaminant sources for each of the three Spacelab configurations.

These sources are treated as closed form mathematical expressions which physically approximate the contaminant emission processes involved. A parametric summary of the methodology and assumptions utilized in the modeling of these sources and the primary considerations involved in determining the major expressions and relationships are presented in the following



LEGEND

Line-of-Sight	Degrees Off +Z	Degrees Off +X
1	0	0
2	30	0
3	60	0
4	30	45
5	60	45
6	30	90
7	60	90
8	30	135
9	60	135
10	30	180
11	60	180
12	30	225
13	60	225
14	30	270
15	60	270
16	30	315
17	60	315

Figure 3. Modeled Spacelab Lines-of-Sight

paragraphs. It should be noted that it was determined through the modeling activities, that the major contaminant transport mechanism of concern to Spacelab and its payloads will be the phenomena of return flux through ambient interaction since most Spacelab/payload sensitive surfaces will not have direct lines-of-sight to the contaminant sources.

2.1.2 a. Outgassing - Nonmetallic materials outgassing is modeled as a continuous Lambertian contaminant source with an emission rate that is a direct function of surface temperature and time of exposure to the vacuum of space. The ESA design of the external Spacelab thermal control system has apparently been finalized and isothermal total mass loss/volatile condensible material (TML/VCM) test data on the chosen nonmetallic materials has been supplied by ESA. The current Spacelab passive thermal control system design incorporates Chemglaze II A-276 white paint (Hughson Chemical Company, Erie, Pennsylvania) as the thermal control coating for all internal and external pallet surfaces and multilayer insulation (MLI) manufactured by Aeritalia as the thermal blanket for the module and tunnel sections of Spacelab.

ESA thermal vacuum test data on these materials is contained in References 10 and 11, respectively. Figure 4 depicts the variation of Chemglaze and MLI TML rates and outgassing rates as a function of vacuum exposure time at a test temperature of $80^{\circ}C$. Outgassing rates for these materials were determined from the % VCM data for a $-75^{\circ}C$ Quartz Crystal Microbalance (QCM) deposition monitor by assuming that the sticking coefficient of the large molecular weight outgassing species was unity at that temperature. Chemglaze II % VCM data [10] was presented as total % VCM for the entire 165 hour test, therefore, only the average outgassing rate could be determined. In contrast, % VCM data on the MLI[11] was presented in terms of % VCM $\cdot$ s^{-1} and the MLI outgassing decay curve could be established.

The average outgassing rates at $125^{\circ}C$ (OGR_{125}) derived from the ESA supplied test data in $g{\cdot}cm^{-2}{\cdot}s^{-1}$ were $1.33x10^{-11}$ for Chemglaze II and $1.29x10^{-9}$ for the module MLI. Outgassing rates are input to the SPACE Program at the $125^{\circ}C$ reference temperature and are then adjusted internally to the model for individual nodal surface temperatures. The analytical expression developed to describe this temperature dependence for each material is presented below:

$$OGR_T = OGR_{125} \bullet EXP\ (T-125)/K, \qquad (1)$$

where, T = source temperature ($^{\circ}C$) and

K = material characteristic constant which

= 20 for Chemglaze and

= 11 for MLI.

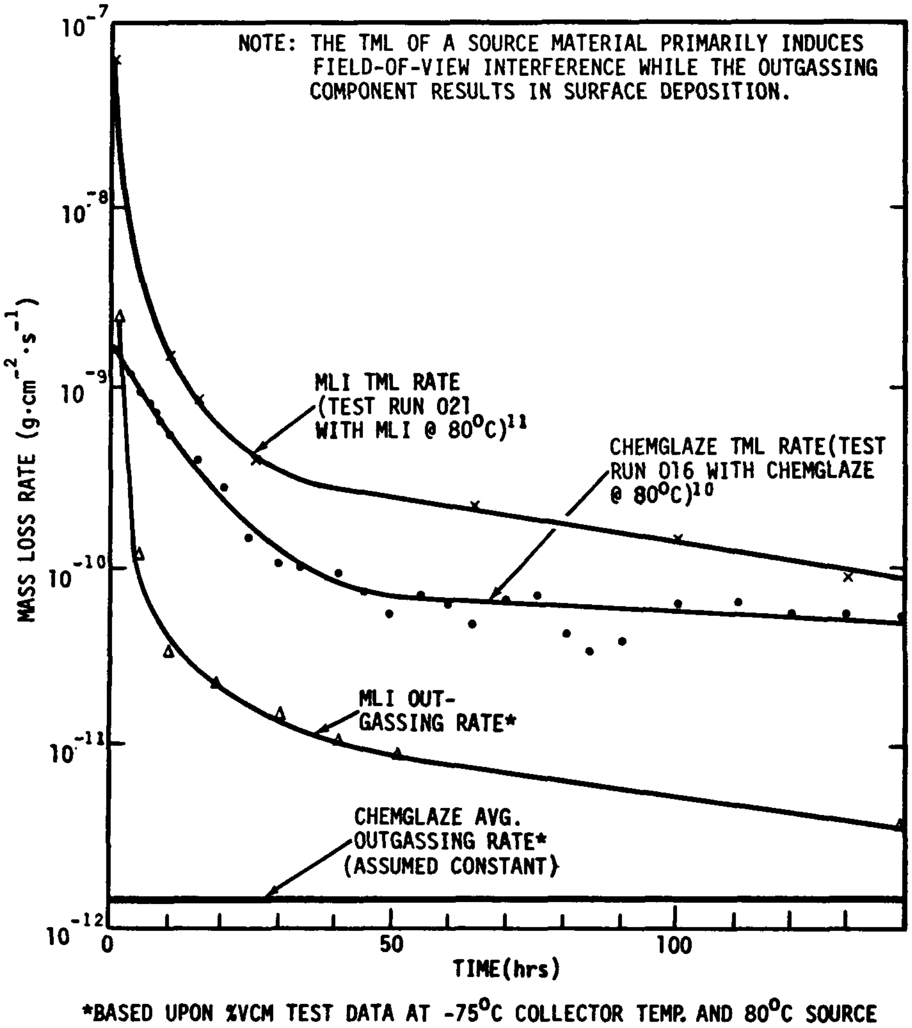


Figure 4. MLI and Chemglaze II Mass Loss Rate Variation with Time

By utilizing the ESA obtained % VCM data at differing QCM temperatures, the outgassing component sticking coefficient variation with temperature was approximated for the MLI and Chemglaze II coatings. Again by assuming that the sticking coefficient approaches unity at $-75^{\circ}C$, sticking coefficients at other temperatures are simply the ratios of the % VCM at temperature T_c over the % VCM at $-75^{\circ}C$. Figure 5 presents the sticking coefficient variation with collector temperature, T_c, for MLI and Chemglaze II held at $T_s = 80^{o}C$. Superimposed on Figure 5 is the Skylab derived sticking coefficient relationship used in previous analyses for comparison.

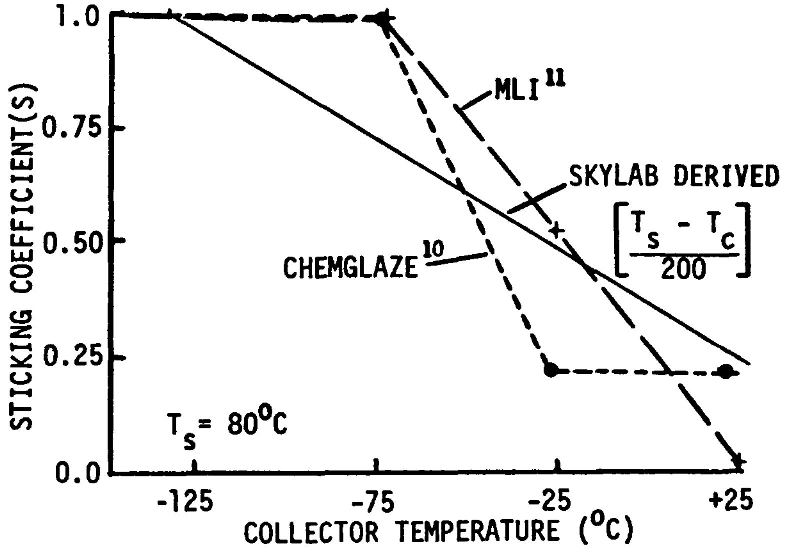


Figure 5. MLI and Chemglaze II Sticking Coefficient Relationships

2.1.2 b. Early Desorption - A similar approach is utilized in modeling the phenomena of early desorption, however, in contrast to outgassing; the early desorption rate tends to decay more rapidly upon initial exposure to space vacuum. The ESA test data depicted in Figure 4 was again used to establish the required SPACE Program model input parameters. Primary constituents of early desorption and their mole fractions include: water (0.57), nitrogen (0.23), carbon dioxide (0.12) and oxygen (0.08). The results presented later in this paper are based upon the early desorption rates at 10 hours into the decay curve. The 10 point was selected to obtain worst case predictions for payloads at the point in a mission when activation of susceptible instruments might be expected to commence. The modeled early desorption rates at 100^oC (EDR_{100}) in $g \cdot cm^{-2} \cdot s^{-1}$ were $1.29x10^{-9}$ for Chemglaze II and $4.43x10^{-9}$ for MLI at 10 hours with their temperature dependence modeled as

$$EDR_T = EDR_{100} \bullet EXP \; \frac{E}{R}\left[\frac{1}{373} - \frac{1}{T}\right], \qquad (2)$$

where, T = source temperature (^{o}K) and

E = source activation energy (7500 cal·mole^{-1} assumed).

2.1.2 c. Cabin Atmosphere Leakage - Cabin atmosphere leakage is limited to the pressurized volumes of the LMOP and SMTP Spacelab configurations. For those pressurized volumes, which include the module and tunnel segments only, leakage is modeled as a Lambertian source being emitted uniformly from their external surfaces. Leakage is modeled as a constant steady state source for the LMOP and SMTP pressurized volume surfaces at a rate of 1.35 kg per day having the following mole fractions of molecular constituents: nitrogen (0.758), oxygen (0.219), carbon dioxide (0.007) and water (0.016).

2.1.2 d. Spacelab Condensate Vent - The SCV, located on the upper forward cone of the Spacelab module, is a controllable overboard liquid dump system which emits condensed water and trace atmospheric contaminants at a nominal flowrate of 4.5 kg·min^{-1}. The SCV is scheduled for only one operation of 7 to 17 minutes duration for each seven days on-orbit, therefore, timelining of the SCV for contamination avoidance should not be difficult. The nozzle design of the SCV is similar to that of the Skylab contingency condensate vent employing a double-tapered exit orifice 2.45 mm in diameter and a heater system to inhibit nozzle freeze-up.

The SCV will produce copious amounts of ice/water particles and water vapor (approximately 15% by weight) during operation. The primary contamination concern other than proper timelining is the potential frost layer/snowcone buildup on Orbiter and Spacelab structural surfaces resulting from SCV plume impingement. This would result in an additional unpredictable contaminant source which would be impossible to control. Dornier Systems small vacuum chamber test data on the SCV illustrated in Figure 6 indicates that plume impingement on the Orbiter payload bay forward bulkhead has been minimized but not totally eliminated for the most forward Spacelab module positions within the bay. The main core and lower density region of the SCV plume will be confined to approximately a 22^{o} conical half angle, however, the over expanded vapor region of the plume distribution pictured may have been restricted by the confines of the small (0.4 m diameter) test chamber employed. This should present negligible problems although, as a precaution, it might

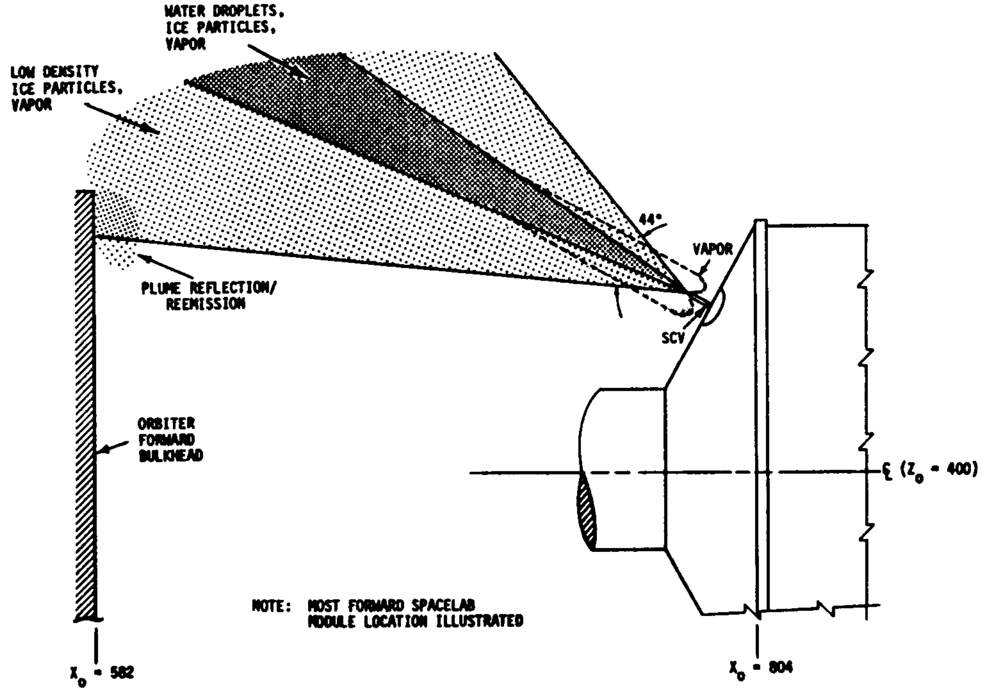


Figure 6. Spacelab Condensate Vent Plume Definition

be advisable to allow the payload bay area to heat soak under solar exposure during venting to minimize condensation.

3. SPACELAB MOLECULAR INDUCED ENVIRONMENT PREDICTIONS

Through the use of the SPACE Program, molecular induced environment predictions were established for the three modeled Spacelab configurations (i.e.; long module/one pallet-LMOP, short module/three pallet-SMTP and five pallet-FIVP) and for the contaminant sources described in subsection 2.1.2. The contaminant sources evaluated in detail in this section include nonmetallic materials outgassing, early desorption at 10 hours of vacuum exposure and cabin atmosphere leakage. The Spacelab condensate vent has been evaluated in detail in Reference 13 and is not specifically reiterated herein since plume structural impingement has been minimized and due to the condensate system's capability of holding condensate for up to seven days which will facilitate vent timelining. Although the experiment vacuum vent has been identified as an additional major contaminant source, sufficient supplemental design/test data is not yet available, and consequently the evaluation of this source has not been extended. The experiment vacuum vent must be evaluated on a "per experiment" basis since its contamination source characteristics are dependent upon the particular experiment using the vent facility. Interference with the operation of sensitive Spacelab payloads by these vent sources should easily be avoided through vent expulsion timelining around the data acquisition periods of payloads susceptible to the induced contaminant cloud and through employing protective measures such as operable covers and ambient drag vector avoidance by cryogenic payloads.

The induced environment predictions for the Spacelab configurations presented have been formatted to be compatible with the baseline contamination control criteria[4] as interpreted by the Contamination Requirements Definition Group (CRDG) at MSFC[6]. This criteria serves as the basis of the Spacelab contamination control criteria evaluation presented in Section 4 and for the recommendations included therein.

3.1 Molecular Number Column Density (NCD) Predictions - Seventeen fixed lines-of-sight for each Spacelab configuration are currently in the SPACE Program for which current NCD predictions have been made. These lines-of-sight (illustrated for the SMTP in Figure 3) encompass the 120° conical viewing volume centered around the +Z axis above the Spacelab vehicle originating at the CRDG Prime Measurement Point (PMP) at $X_o = 1107$, $Y_o = 0$ and $Z_o = 507$. These predictions are presented in Table I for the three modeled Spacelab configurations. Nonmetallic surface material mass loss predictions are based upon the maximum hot case Spacelab thermal profile data contained in Reference 14 and the ESA materials test data previously discussed.

The primary concern of the NCD parameter is its propensity to scatter, emit or absorb radiant energy thus interferring with the data acquisition ability of sensitive optical experiments. The corresponding contaminant pressures in the proximity of high voltage power systems can also induce such phenomena as corona arc-over damage and multipacting of transmitting systems. The predicted NCD levels for outgassing and leakage will remain relatively constant throughout a Spacelab mission, however, the early desorption NCD levels will decrease rapidly as the early desorption rate decays with time of vacuum exposure. The primary contamination threats from early desorption will, therefore, be limited to the initial on-orbit phases of a given mission.

Table I. Spacelab Molecular Number Column Density Predictions

SOURCE/ CONFIG. / LINE-OF-SIGHT	NUMBER COLUMN DENSITY (molecules·cm^{-2})							
	OUTGASSING			EARLY DESORPTION			LEAKAGE	
	LMOP	SMTP	FIVP	LMOP	SMTP	FIVP	LMOP	SMTP
1	1.9E8*	2.8E8	1.3E8	3.7E12	1.8E12	2.1E11	2.6E12	1.4E12
2	1.6E8	2.4E8	1.2E8	3.0E12	1.5E12	1.9E11	2.2E12	1.1E12
3	1.6E8	2.2E8	1.1E8	2.7E12	1.4E12	1.7E11	1.9E12	9.9E11
4	1.7E8	2.5E8	1.3E8	3.3E12	1.6E12	2.0E11	2.3E12	1.2E12
5	1.6E10	1.5E9	1.2E8	3.4E12	1.5E12	1.8E11	2.1E12	1.0E12
6	1.3E9	5.2E8	1.3E8	3.9E12	1.8E12	2.1E11	2.6E12	1.4E12
7	3.4E10	3.9E9	1.2E8	5.1E12	2.0E12	1.8E11	2.6E12	1.3E12
8	7.2E8	6.6E8	1.4E8	4,8E12	2.3E12	2.2E11	3.1E12	1.7E12
9	3.7E10	7.4E9	1.5E8	7.5E12	3.4E12	2.3E11	3.7E12	2.2E12
10	1.1E9	9.6E8	1.5E8	5.1E12	2.6E12	2.3E11	3.3E12	1.9E12
11	1.1E10	2.7E9	1.7E8	8.4E12	4.4E12	2.7E11	4.5E12	3.3E12
12	6.9E8	6.5E8	1.4E8	4.4E12	2.2E12	2.2E11	3.1E12	1.7E12
13	3.7E10	7.3E9	1.4E8	6.4E12	3.0E12	2.2E11	3.7E12	2.2E12
14	1.3E9	5.1E8	1.3E8	3.5E12	1.7E12	2.0E11	2.6E12	1.4E12
15	3.4E10	3.9E9	1.1E8	4.4E12	1.7E12	1.7E11	2.6E12	1.3E12
16	1.6E8	2.4E8	1.2E8	3.1E12	1.5E12	1.9E11	2.3E12	1.2E12
17	1.6E10	1.5E9	1.1E8	3.1E12	1.4E12	1.7E11	2.1E12	1.0E12

*1.9E8 = 1.9×10^{8}

3.2 Molecular Return Flux Predictions - For most Spacelab payloads, the primary transport mechanism of the major contaminant sources will be the return flux resulting from contaminant molecular collisions with the ambient atmosphere flux. Direct line-of-sight and self-scattering return flux transport were evaluated and deemed negligible under the major Spacelab source conditions. All major Spacelab sources were evaluated for maximum return flux (i.e.; ambient drag vector perpendicular to surface of interest) to a 2π steradian field-of-view surface located at the PMP. The worst case orbital altitudes were considered for each source modeled (i.e., early desorption and leakage at 200 km and outgassing at 250 km) and medium solar activity was assumed. The resulting predictions are presented in Table II.

The main threat of molecular return flux is its ability to accommodate or stick to surfaces upon which it impinges thus absorbing radiant energy which scientific instruments are attempting to detect or modifying the thermal characteristics of surfaces to which it adheres. The constituents of early desorption and cabin leakage return flux will demonstrate negligible dwell times on all surfaces other than those that are cryogenic. In contrast, outgassing species can condense on surfaces with temperatures of 25°C or warmer.

Table II. Spacelab Molecular Return Flux Predictions

SOURCE/ ALTITUDE CONFIGURATION	MAXIMUM RETURN FLUX-2π sr SURFACE (molecules·cm^{-2}·s^{-1})		
	OUTGASSING AT 250 km	EARLY DESORPTION AT 200 km	LEAKAGE AT 200 km
LMOP	8.7E11	5.0E14	4.1E14
SMTP	1.6E11	2.4E14	2.1E14
FIVP	1.4E10	2.4E13	——

The optimum approach to decreasing the impacts of return flux upon sensitive surfaces is to minimize surface impingement or reduce its ability to stick. Impingement can be minimized through proper selection of materials with low early desorption rates, flying in attitudes where major contributing surfaces are cool, flying in attitudes where return flux is minimized, by the payloads supplying their own operable protective covers or in some cases by providing an inert gas purge system.

3.3 Deposition Predictions - Spacelab deposition predictions calculated by the SPACE Program were based upon the mission dependent parameters set forth in the CRDG interpretations[6] of the existing Spacelab contamination control criteria[5]. These parameters include condensible deposition on a 0.1 steradian surface at 300°K (27°C) located at the PMP subject to a random drag vector orientation for a seven day mission. Sticking coefficient data employed in the modeling was based upon the ESA TML/VCM test data discussed in subsection 2.1.2. Materials outgassing is the only identified Spacelab contaminant source that will accumulate in measurable quantities on a surface at 27°C, therefore, the deposition predictions which are presented in Table III result from that source alone. Although the predicted levels of outgassing deposition resulting from Spacelab carrier sources equate to less than one angstrom in thickness for a 0.1 steradian surface at the PMP at 300°K, deposition will still be of concern for certain payloads with differing configurations and temperature profiles.

Table III. Spacelab Molecular Deposition Predictions

PARAMETER / CONFIGURATION	DEPOSITION (0.1 sr surface, 250 km, 27°C)		
	RATE	ACCUMULATIVE - 7 DAY MISSION	
	(molecules·cm^{-2}·s^{-1})	(molecules·cm^{-2})	Å
LMOP	8.61×10^7	1.26×10^{13}	0.21
SMTP	1.69×10^8	2.47×10^{13}	0.41
FIVP	1.33×10^8	1.94×10^{13}	0.32

4. SPACELAB CONTAMINATION CONTROL CRITERIA EVALUATION

The induced environment predictions presented in the previous subsection in conjunction with supplemental analysis were utilized to determine the ability of the various Spacelab configurations to meet the existing contamination control criteria imposed upon Spacelab[4] and to establish Spacelab design and development requirements to insure that the criteria are satisfied. To accomplish this, each major Spacelab contaminant source was evaluated against the five criteria statements based upon the interpretations and assumptions sanctioned by the CRDG in Reference 6. In the ensuing subsections, each main criteria statement is presented as depicted in Reference 4. Each is then followed by the applicable CRDG interpretations and finally a detailed analysis of the Spacelab contaminant sources.

4.1 Induced Particulate Environment - *It is a design and operational goal for Spacelab to control in an instrument field-of-view particles of 5 microns in size to one event per orbit.* This assumes a field-of-view of 1.5×10^{-5} steradian and is restricted to particles within 5 km of the spacecraft.

In determining the induced particulate environment of a manned spacecraft such as the Spacelab carrier, known defined particulate sources like the Spacelab condensate vent (SCV) can be parametrically analyzed in a closed mathematical form by knowing the primary vent system characteristics (based upon existing system test data or detailed stream tube vent plume and freezing analysis) and integrating these into an appropriate particle trajectory analysis program. This was conducted for the SCV and the acquired results indicate that this criteria statement can be exceeded during and for up to a minimum time increment of 17 minutes after SCV operation. Under this condition, the intent of the criteria can be met through timelining of the SCV overboard dump around operations of payloads that have been determined susceptible to particles in their field-of-view. Current planning is for the SCV to be operated only once per each seven days on orbit, therefore, noninterference timelining should create minimal problems.

In contrast to well defined controllable particulate sources such as the SCV, intermittent particulate sources (i.e., unpredictable surface/source random particle emission) present a more difficult analytical problem. This phenomena, too, was evaluated and it suffices to state that the current contamination control criteria as applied to random particulate emissions may be very difficult for the Spacelab carrier to meet based upon limited particle sighting data obtained during the Skylab Program by the S052 White Light Coronagraph experiment.

4.2 <u>Molecular Column Density</u> - *It is a design and operational goal for Spacelab to control induced water vapor column density to 10^{12} molecules$\cdot$cm^{-2} or less.* This is measured along any vector within 60 degrees of the +Z axis originating at the Prime Measurement Point (PMP) (X_o = 1107, Y_o = 0 and Z_o = 507). It is further assumed that this represents the worst case situation.

The modeled sources which are of concern to meet the NCD criteria include the SCV, early desorption of externally exposed Spacelab surfaces and the leakage of cabin atmosphere from the pressurized Spacelab module/tunnel segments. No control is required for outgassing materials as stated by this criteria since this source is considered to contain no water constituents (i.e., the outgassing contaminant sources meet the NCD criteria statement).

The SCV exceeds the NCD criteria by over 3 orders of magnitude during its operation and must be timelined around the operation of those payloads deemed susceptible to water column densities greater than 10^{12} molecules$\cdot$cm^{-2} in order that the intent of the criteria be met. Since this overboard dump is currently planned to occur only once each seven days on orbit, interference with payload operations should be minimal if properly timelined.

In the evaluation of the leakage contaminant source, the worst case line-of-sight prediction within 60 degrees of the +Z axis is for the LMOP line-of-sight 11 where the total NCD = 4.46×10^{12} molecules·cm^{-2} and the water vapor NCD = 7.14×10^{10} molecules·cm^{-2} (see Table I). This value is well within the criteria limits and, therefore, leakage is in compliance.

The final contaminant source, early desorption, demonstrates a maximum total NCD of 8.4×10^{12} molecules·cm^{-2} for the LMOP line-of-sight 11 at 10 hours into a mission. This equates to a 4.1×10^{12} molecules·cm^{-2} NCD for water vapor which exceeds the criteria limit. In order to meet the intent of the NCD criteria for early desorption, it will be necessary for the external Spacelab surfaces to demonstrate an average early desorption rate (EDR) of less than 2.1×10^{-8} g·cm^{-2}·s^{-1} at 100°C. This can be accomplished through selection of external materials having an EDR less than this value, through decreasing the total area of coverage of high early desorbing materials or by delaying data acquisition by susceptible instruments until the NCD levels for water vapor have decayed to less than 10^{12} molecules·cm^{-2}. Based upon the ESA supplied materials test data, this delay time could be as high as 24 hours. This is highly dependent upon the thermal history of surfaces during that period, however, it is assumed that an average delay time of 24 hours will bring the early desorption NCD levels into compliance with the criteria.

4.3 <u>Molecular Return Flux</u> - *It is a design and operational goal for Spacelab to control return flux to 10^{12} molecules·cm^{-2}·s^{-1}.* This refers to the total flux on an unshielded surface (2π steradian acceptance) oriented in the +Z direction at the PMP under worst case situations.

The stated criteria applies to the summation of return flux from all contaminant sources with no specific stipulations on the separate constituent levels allowable. However, the ensuing evaluation accounts for the acceptable source levels to meet the criteria on an individual basis. It is realized that from a practical viewpoint that each source should be allowed only a budgeted percentage of the total. This same consideration should also be applied to the Orbiter sources (which are not accounted for herein) to budget between Spacelab and Orbiter source levels. However, for the basic Spacelab design and development analytical approach which has been previously acceptable, it is assumed that each source may have an allowable return flux level of 10^{12} molecules$\cdot$cm$^{-2}\cdot$s^{-1} or less. It should be noted that if the design and operational recommendations in the ensuing paragraphs are followed, that the 10^{12} molecules$\cdot$cm$^{-2}\cdot$s^{-1} total return flux criteria will inherently be met.

The molecular return flux levels experienced during SCV operation significantly exceed the stated criteria limits (i.e. 1.4×10^{17} molecules$\cdot$cm$^{-2}\cdot$s^{-1}). Sensitive surfaces should be protected from return flux possibly by utilizing operable covers, if practical, while SCV dumps are in progress. Return flux could also be minimized through vehicle attitude selection which is not conducive to return flux during SCV operation. Ideally, such an attitude would place the ambient drag vector continually in the Spacelab +Z direction, thus reducing return flux to the PMP to almost zero.

The worst case Spacelab configuration for both outgassing and early desorption return flux to a 2π steradian surface at the PMP is the LMOP during the maximum temperature profile attitude (see Table II). The outgassing return flux prediction for the Spacelab LMOP under maximum ambient drag vector orientation is 8.7×10^{11} molecules$\cdot$cm$^{-2}\cdot$s^{-1} at 250 km altitude. The LMOP return flux prediction therefore meets the criteria.

Utilizing a similar approach for early desorption, it was determined that the maximum LMOP return flux rate would be 5.0×10^{14} molecules$\cdot$cm$^{-2}\cdot$s^{-1} based upon the 200 km altitude predictions. To meet the return flux criteria for early desorption, the EDR would have to be less than 9.22×10^{-11} g$\cdot$cm$^{-2}\cdot$s^{-1} at 100°C assuming that all external Spacelab surfaces contribute. As in the case of early desorption compliance with the NCD criteria statement, the intent of the return flux criteria can be met for susceptible payloads if the exposure of their sensitive surfaces is delayed until such time that the early desorption return flux rate has decayed through vacuum exposure to an acceptable level (approximately 35 hours). If practical, susceptible surfaces should provide their own protective devices such as operable covers and the maximum ram vehicle attitudes should be avoided during the Spacelab early mass loss period. Selection of orbital altitudes above approximately 600 km would also reduce the return flux to an acceptable level.

Meeting the intent of the return flux criteria for cabin atmosphere leakage may be more difficult to achieve due to its continuous, uncontrollable characteristics. Predictions for the worst case Spacelab leakage configuration, LMOP, indicate a return flux to a 2π steradian surface at the PMP of 4.1×10^{14} molecules$\cdot$cm$^{-2}\cdot$s^{-1} at 200 km altitude which exceeds the criteria. Decreasing the allowable design leak rate of the Spacelab vehicles could be extremely costly to the program and such an approach is somewhat impractical in that only 3.29 g$\cdot$day^{-1} could be allowed to leak to insure criteria compliance. Realistically, leakage return flux should not impact any exposed surfaces other than possibly such cryogenic systems as the LHe Infrared Telescope which will have an acceptance angle much less than 2π steradian (closer to 0.1 steradian). However, as stated, the return flux criteria is exceeded. The levels for leakage return flux can be decreased by utilizing previously suggested methods of surface protection, attitude and orbital altitude selection (above 600 km).

4.4 Background Brightness - *It is a design and operational goal for Spacelab to control continuous emissions or scattering to not exceed 20th magnitude$\cdot$s^{-2} in the UV range.* This is equivalent to $10^{-12} B_\odot$ at a wavelength of 360 nonometers ($B_\odot$ = solar brightness).

Background brightness induced by the scattering or emission of radiant energy can result from the presence of either contaminant particles or molecules within the field-of-view of a sensitive optical instrument. For the modeled Spacelab molecular contaminant sources, the primary phenomena of concern in this regard is the scattering of solar energy from the irradiated contaminant molecules. Analyses of this phenomena for outgassing, early desorption and cabin leakage have indicated that all will be well within the criteria as stated.

Although approximately 15% of the vent effluents from the SCV will be emitted in the form of water molecules, the greater concern of this source with regard to the background brightness criteria will be the scattering and emission from the generated ice particles. Due to its potential production of many particles in the submicron region where the scattering level can be significant, exceeding this criteria during vent operations is highly probable. For this reason, the SCV overboard dumps should be timelined to avoid interference with sensitive Spacelab payload data acquisition.

4.5 Absorption Due to Condensible Deposition - *It is a design and operational goal for Spacelab to control to 1% the absorption of UV, visible and IR radiation by condensibles on optical surfaces.* This refers to the objective of an optical system that would typically have a dielectric surface at ambient temperature (approximately 300°K) that is located at the PMP, is oriented along the +Z axis and has an acceptable of 0.1 steradian. It is also assumed that this is for a 7 day mission with random orientation of the ambient drag vector.

Evaluation of this criteria statement indicates that the only major modeled Spacelab contaminant source presenting a concern for absorption by condensibles under the above stated assumptions is the outgassing of Spacelab external nonmetallic materials. This is due to the fact that negligible amounts of the other evaluated source constituents will stick to a surface at 300°K for any measurable time period. To analyze the phenomena of outgassing deposition, a systematic approach was taken utilizing the predictions contained in Table III which are based upon the above stated assumptions. Since this criteria statement is based upon the contaminant effect rather than a specific contaminant level, a more comprehensive evaluation is necessary to determine the compliance of the model predictions with the criteria limits.

The results of this evaluation indicate that the maximum absorption due to condensibles will be induced by the SMTP Spacelab configuration. By assuming that the sensitive surface would be a reflective optic detecting at 1500Å wavelength, the maximum absorption due to outgassing deposition would be 0.16% under the conditions evaluated. This is well within the criteria limits and consequently the Spacelab design as modeled is in compliance.

4.6 Evaluation Summary - To facilitate the interpretation of the preceding criteria evaluation, with respect to Spacelab design/development control, the major results and conclusions are summarized herein. From this, certain program overview design and development directions can be made concerning the major modeled Spacelab contaminant sources and preliminary design/operational requirements. These include:

a. The contaminant source of outgassing meets all of the CRDG Spacelab design criteria statements evaluated as based upon the supplied test data from ESA.

b. The most restrictive criteria statement for Spacelab early desorption is that for return flux. An early desorption rate of less than 9.2×10^{-11} $g \cdot cm^{-2} \cdot s^{-1}$ at $100^{o}C$ will result in compliance with the criteria. If materials control to this level proves impractical from a design viewpoint, activation and/or exposure of payloads sensitive to the early desorption induced environment should be delayed up to 35 hours until early desorption has decayed to an acceptable level.

c. Cabin atmosphere leakage cannot from a practical point of view be controlled to a satisfactory level of compliance with the return flux criteria through Spacelab design alone. For Spacelab missions on which instruments that are sensitive to this phenomena are to be flown, the impact of leakage can be minimized through proper selection of orbital altitude, attitude and sensitive surface protective devices such as operable covers. For a vast majority of proposed Spacelab payloads, other than those operating at cryogenic temperatures, the impact of the predicted levels of return flux of cabin atmosphere leakage will be negligible.

d. During its operation, the SCV will exceed all of the criteria statements with the exception of the 1% absorption due to condensibles. This source cannot be controlled through design without major system modifications such as storing the condensate rather than expelling it overboard. The logical approach to complying with the intent of the criteria statements by the SCV would be to timeline venting to avoid interference with sensitive payload data acquisition and protect sensitive surfaces during vent operations.

In a general overview it can be stated that the current Spacelab design is acceptable from a contamination view point if the users of Spacelab are aware of the environment to which they will be exposed and the constraints/precautions necessary to insure that contamination does not compromise their instruments. It should also be noted that the conclusions presented herein have been based solely upon the Spacelab design and that the additional Orbiter sources must also be considered by any STS/Spacelab user.

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